EFFECTS OF ALIGNMENT OF REINFORCEMENT MATERIAL TO THE PROPERTIES OF POLYMER MATRIX COMPOSITE (PMC)

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ABSTRACT

This thesis investigated the effect of alignment of reinforcement material to the properties of polymer matrix composite (PMC). Tensile test and water absorption test were conducted in order to study the properties of polymer matrix composite (PMC) when the alignment of reinforcement material was varied. For this project, woven roving fiberglass was used as the fiber and unsaturated polyester resins as its matrix material. Hand layup process was used to fabricate the laminated composite. The specimens were divided into four major categories with different alignment and thickness of fiber and matrix which were 5 layers bidirectional, 5 layers multidirectional, 7 layers bidirectional, and 7 layers multidirectional. Tensile test showed that bidirectional alignment was better in term of mechanical properties compared to multidirectional alignment. The 5 layers bidirectional have a higher tensile strength compared to 5 layers multidirectional. While 7 layers bidirectional have a higher tensile strength compared to 7 layers multidirectional. The modulus of elasticity of bidirectional alignment was higher than multidirectional alignment. Bidirectional alignment was better because the external tensile load was equally distributed on all the fibers and transmitted along the axis of the fibers. Whereas in case of multidirectional alignment, fiber axes was non-parallel to load axis, resulting in off axis pulling of fibers and increased stress concentration causing the earlier failure of laminates. Water absorption test showed that multidirectional alignment absorbs more quantity of water compared to bidirectional alignment. Therefore, multidirectional alignment was not suitable for underwater application such as boat, canoe and yacht. It can be conclude that, the properties of PMC is depends on the alignment of reinforcement material.

ABSTRAK

Tesis ini menyiasat kesan jajaran bahan tetulang kepada sifat-sifat komposit matriks polimer (PMC). Ujian tegangan dan ujian penyerapan air telah dijalankan untuk mengkaji sifat-sifat komposit matriks polimer (PMC) apabila penjajaran bahan tetulang telah diubah. Untuk projek ini, gentian kaca yang ditenun telah digunakan sebagai bahan tetulang manakala Poliester tak tepu digunakan sebagai bahan matriks. Proses hamparan tangan telah digunakan untuk memalsukan komposit berlapis. Spesimen telah dibahagikan kepada empat kategori utama dengan penjajaran yang berbeza dan ketebalan gentian dan matriks iaitu 5 lapisan dwi arah, 5 lapisan berbilang arah, 7 lapisan dwi arah, dan 7 lapisan berbilang arah. Ujian tegangan menunjukkan, penjajaran dwi arah adalah lebih baik dari segi sifat mekanikal berbanding penjajaran berbilang arah. 5 lapisan dwi arah mempunyai kekuatan tegangan yang lebih tinggi berbanding dengan 5 lapisan berbilang arah manakala 7 lapisan dwi arah telah kekuatan tegangan yang lebih tinggi berbanding dengan 7 lapisan berbilang arah. Modulus keanjalan penjajaran dwi arah adalah lebih tinggi daripada penjajaran berbilang arah. Penjajaran dwi arah adalah lebih baik kerana beban tegangan luar telah sama rata ke atas semua gentian dan dihantar sepanjang paksi gentian. Manakala dalam penjajaran berbilang arah, paksi gentian adalah tidak selari dengan beban paksi, menyebabkan dalam paksi menarik gentian dan tumpuan tegasan meningkat menyebabkan kegagalan awal laminat. Ujian penyerapan air menunjukkan bahawa penjajaran berbilang arah menyerap kuantiti yang lebih banyak air berbanding penjajaran dwi arah. Oleh itu, penjajaran berbilang arah tidak sesuai untuk aplikasi di bawah air seperti kanu, bot, dan kapal layar. Kesimpulan boleh dibuat bahawa, sifat-sifat matriks polimer komposit adalah bergantung kepada penjajaran bahan tetulang.

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LIST OF SYMBOLS

E	Young's Modulus
σ	Stress
ε	Strain
ρ	Density
V	Volume

LIST OF ABBREVIATIONS

PMC	Polymer Matrix Composite
MMC	Metal Matrix Composite
CMC	Ceramic Matrix Composite
PEEK	Polyetheretherketone
PPS	Polyphenylenesulfide
FRP	Fiber Reinforced Plastic
GFRP	Glass Fiber Reinforced Plastic
TPEs	Thermoplastic elastomers
UTS	Ultimate Tensile Strength
Si	Silicon
O	Oxygen
Al	Aluminium
Ca	Calcium
B	Boron
Mg	Magnesium

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Nowadays, composite materials are the well known material that has been used in manufacturing industry. The range of application is very large, from the aerospace to the automotive industry, from household product to optical devices and many other more application. Composite materials have just started to dominate the future engineering reality of the twenty first century. Lata (2011) stated that the first uses of composites date back to the 1500s before century when early Egyptians and Mesopotamian settlers used a mixture of mud and straw to create strong and durable buildings.

Composite material is one which is composed of at least two elements working together to produce material properties that are different to the properties of those elements on their own. The majority of composites are made up of a continuous phase called a matrix in which a stronger phase consisting of fiber or particles is embedded. Fundamentally, fiber or particles distributed through a matrix to enhance the properties of the matrix in some way. Polymer matrix composites (PMC) first emerged as a distinct technology in an era when improved performance for advanced military systems provided a primary motivation for materials development.

Laminated polymer matrix composites are nowadays widely used in structural applications. Their most important properties are clearly the high longitudinal modulus and tensile strength, which result from outstanding fiber properties. In fact, the most common multidirectional laminates can usually sustain

increasing loads after extensive transverse cracking in various plies, but fiber fracture generally causes overall failure.

The aim of this study is to determine the effect of alignment of reinforcement material to the properties of Polymer Matrix Composite (PMC). The properties such as stress, strain, Young's Modulus and water absorption property, play an important role in producing the good and best quality of PMC. It is therefore important in term of scientific and practical point of view, to understand the effect of alignment of reinforcement material to the properties of Polymer Matrix Composite (PMC).

1.2 OBJECTIVES

Basically the purposes in accomplishing this study are listed as below:

(i) To study the effect of different alignment of reinforced material to the properties of Polymer Matrix Composite (PMC).
(ii) To evaluate the water resistance using different alignment towards seawater.

1.3 PROBLEM STATEMENT

Numerous applications have been proposed and demonstrated for producing align-fiber composite. Several processes have been patented to produce align-fiber composite. Usually, the primary driving force for using composite materials is a combination of features such as reduced weight, improved mechanical properties, and resistance to chemical attack. At first, their special properties led aligned-fiber composite materials to be considered primarily for specialty applications. However, nobody had stated a right procedure to align the fiber in order to optimize the properties of PMC such as its strength and water absorption property. So this studies being conducted in order to find the best alignment of reinforcement material in order to optimize the properties of PMC in its application in the industry.

1.4 PROJECT SCOPES

In order to achieve the objectives notified earlier, the following scopes have been identified:

(i) Unsaturated polyester had been used as a matrix material and woven roving as a reinforcement material.

(ii) The fabrication of specimens was by hand lay-up process.

(iii) The thicknesses were five layers thickness and seven layers thickness respectively.

(iv) Two types of alignment of reinforcement material which were bidirectional alignment which a combination of 0° and 90° and the other one was multidirectional alignment which a combination of 0°, 30°, 60°, and 90° respectively.

(v) Two types of testing to study the properties of PMC which were tensile test (ASTM D3039M) and water absorption test (ASTM D570).

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, the importance and application of the composite materials at several sectors will be discussed. This chapter will inquired into the general properties of the components that commonly used to produce polymer composite materials which are fiber glass and polyester. Through this chapter, the details of the composite materials can be understood in depth. The roles of build orientation in mechanical properties of the composite materials also can be studied deeply. Hence, a suitable composition of fiber and resin can be investigated to produce composite materials with better performance.

2.2 COMPOSITE MATERIAL

Composite materials, often shortened to composites or called composition materials, are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct at the macroscopic or microscopic scale within the finished structure. According to David (2000), the term composite could mean almost anything if taken at face value, since all materials were composed of dissimilar subunits if examined at close enough detail. But in modern materials engineering, the term usually refers to a “matrix” material that is reinforced with fibers. For instance, the term “FRP” (for Fiber Reinforced Plastic) usually indicates a thermosetting polyester matrix containing glass fibers, and this particular composite has the lion's share of today's commercial market. Figure 2.1 shows a laminate

fabricated by “crossplying” unidirectional reinforced layers in a 0°-90° stacking sequence. Many composites used today are at the leading edge of materials technology, with performance and costs appropriate to ultra demanding applications such as spacecraft. But heterogeneous materials combining the best aspects of dissimilar constituents have been used by nature for millions of years. Ancient society, imitating nature, used this approach as well: the Book of Exodus speaks of using straw to reinforce mud in brickmaking, without which the bricks would have almost no strength. Roylance (2000). As shown in Table 2.1, the fibers used in modern composites have strengths and stiffnesses far above those of traditional bulk materials. The high strengths of the glass fibers are due to processing that avoids the internal or surface flaws which normally weaken glass, and the strength and stiffness of the polymeric aramid fiber is a consequence of the nearly perfect alignment of the molecular chains with the fiber axis.

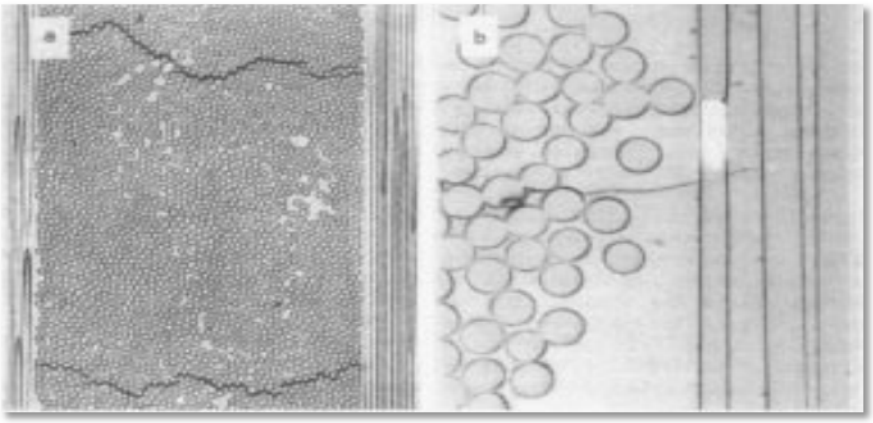

Figure 2.1: A cross plied FRP laminate, showing non uniform fiber packing and micro cracking

Source: Harris, 1986

Table 2.1: Properties of Composite Reinforcing Fibers

Material	***E*** **(GPa)**	**σb (GPa)**	**ϵb (%)**	**ρ (Mg/m^3)**	***E*/ ρ (MJ/kg)**	**σb/ ρ (MJ/kg)**	**Cost ($/kg)**
E-glass	72.4	2.4	2.6	2.54	28.5	0.95	1.1
S-glass	85.5	4.5	2.0	2.49	34.3	1.8	22-33
aramid	124	3.6	2.3	1.45	86	2.5	22-33
boron	400	3.5	1.0	2.45	163	1.43	330-440
HS graphite	253	2.5	1.1	1.80	140	2.5	66-110
HM graphite	520	2.4	0.6	1.85	281	1.3	220-660

Source: Smith (2005)

Of course, these materials are not generally usable as fibers alone, and typically they are impregnated by a matrix material that acts to transfer loads to the fibers, and also to protect the fibers from abrasion and environmental attack. The matrix dilutes the properties to some degree, but even at a very high specific (weight-adjusted) properties are available from these materials. Metal and glass are available as matrix materials, but these are currently very expensive and largely restricted to R&D laboratories. Polymers are much more commonly used, with unsaturated styrene-hardened polyesters having the majority of low-to-medium performance applications and epoxy or more sophisticated thermosets having the higher end of the market. Thermoplastic matrix composites are increasingly attractive materials, with processing difficulties being perhaps their principal limitation.

2.2.1 Types of Composite Material

Generally, composite material can be devided to three main types which are Metal Matrix Composite (MMC), Ceramic Matrix Composite (CMC), and Polymer Matrix Composite (PMC). The different between each type is generally their matrix phase. For example, MMC is a composite material that being fabricated by using metal as matrix constituent. CMC is using a ceramic as a matrix constituent and same goes to PMC that use polymer as a matrix constituent. Each of this type has their

own advantages and disadvantages. For example, CMC materials overcome the major disadvantages of conventional technical ceramics, namely brittle failure and low fracture toughness, and limited thermal shock resistance. Therefore, their applications are in fields requiring reliability at high-temperatures (beyond the capability of metals) and resistance to corrosion and wear. These include:

(i) Heat shield systems for space vehicles, which are needed during the re-entry phase, where high temperatures, thermal shock conditions and heavy vibration loads take place.
(ii) Components for high-temperature gas turbines such as combustion chambers, stator vanes and turbine blades.
(iii) Components for burners, flame holders, and hot gas ducts, where the use of oxide CMCs has found its way.
(iv) Brake disks and brake system components, which experience extreme thermal shock (greater than throwing a glowing part of any material into water).
(v) Components for slide bearings under heavy loads requiring high corrosion and wear resistance.

In addition to the foregoing, CMC can be used in applications, which employ conventional ceramics or in which metal components have limited lifetimes due to corrosion or high temperatures.

Same goes to MMC where it has some advantages which its properties are better than the other material. The applications of MMC include:

a. Carbide drills are often made from a tough cobalt matrix with hard tungsten carbide particles inside.
b. Some tank armors may be made from MMC, probably steel reinforced with boron nitride. Boron nitride is a good reinforcement for steel because it is very stiff and it does not dissolve in molten steel.
c. Some automotive disc brakes use MMC. Early Lotus Elise models used aluminum MMC rotors, but they have less than optimal heat properties

and Lotus has since switched back to cast-iron. Modern high-performance sport cars, such as those built by Porsche, use rotors made of carbon fiber within a silicon carbide matrix because of its high specific heat and thermal conductivity. The 3M company sells a preformed aluminum matrix insert for strengthening cast aluminum disc brake calipers, allowing them to weigh as much as 50% less while increasing stiffness. 3M company has also used alumina preforms for AMC pushrods.

d. Ford offers a MMC driveshaft upgrade. The MMC driveshaft is made of an aluminum matrix reinforced with boron carbide, allowing the critical speed of the driveshaft to be raised by reducing inertia. The MMC driveshaft has become a common modification for racers, allowing the top speed to be increased far beyond the safe operating speeds of a standard aluminum driveshaft.
e. Honda has used aluminum metal matrix composite cylinder liners in some of their engines.
f. Toyota has since used MMC in the Yamaha-designed 2ZZ-GE engine which is used in the later Lotus Lotus Elise S2 versions as well as Toyota car models, including the eponymous Toyota Matrix. Porsche also uses MMCs to reinforce the engine's cylinder sleeves in the Boxster and 911.
g. The F-16 Fighting Falcon uses monofilament silicon carbide fibers in a titanium matrix for a structural component of the jet's landing gear.
h. Specialized Bicycles has used aluminum MMC compounds for its top of the range bicycle frames for several years. Griffen Bicycles also makes boron carbide-aluminum MMC bike frames, and Univega briefly did so as well.
i. Some equipment in particle accelerators such as Radio Frequency Quadrupoles (RFQs) or electron targets use copper MMC compounds such as Glidcop to retain the material properties of copper at high temperatures and radiation levels.
j. Copper-silver alloy matrix containing 55 vol % diamond particles, known as Dymalloy, is used as a substrate for high-power and high density multi-chip modules in electronics for its very high thermal conductivity.

MMC are nearly always more expensive than the more conventional materials they are replacing. As a result, they are found where improved properties and performance can justify the added cost. Today these applications are found most often in aircraft components, space systems and high-end or "boutique" sports equipment. The scope of applications will certainly increase as manufacturing costs are reduced. In comparison with conventional polymer matrix composites, MMCs are resistant to fire, can operate in wider range of temperatures, do not absorb moisture, have better electrical and thermal conductivity, are resistant to radiation damage, and do not display outgassing. On the other hand, MMCs tend to be more expensive, the fiber-reinforced materials may be difficult to fabricate, and the available experience in use is limited.

2.3 INTRODUCTION TO POLYMER MATRIX COMPOSITE (PMC)

Manufacturing PMC is a multibillion dollar industry in the United States. Composite products range from skateboards to components of the space shuttle. The industry can be generally divided into two basic segments, industrial composites and advanced composites. Several of the composites manufacturing processes are common to both segments. The two basic segments are described such as follows:

(i) Industrial composites

a. The industrial composites industry has been in place for over 40 years in the United State. This large industry utilizes various resin systems including polyester, epoxy, and other specialty resins. These materials, along with a catalyst or curing agent and some type of fiber reinforcement (typically glass fibers) are used in the production of a wide spectrum of industrial components and consumer goods: boats, piping, auto bodies, and a variety of other parts and components.

(ii) Advance Composite

a. The Polymer Matrix Composites industry, or advanced composite materials industry, is characterized by the use of expensive, high-performance resin systems and high-strength, high-stiffness fiber

reinforcement. The aerospace industry, including military and commercial aircraft of all types, is the major customer for advanced composites. These materials have also been adopted to be used in the sporting goods suppliers who sell high-performance equipment to the golf, tennis, fishing, and archery markets. While aerospace is the predominant market for advanced composites today, the industrial and automotive markets will increasingly see the use of advanced composites toward the year 2000. At present, both manual and automated processes are employed in making advanced-composite parts. As automated processes become more predominant, the costs of advanced composites are expected to decline to the point at which these materials will be used widely in electronic, machinery, and surface transportation equipment. Suppliers of advanced composite materials tend to be larger companies capable of doing the research and development necessary to provide the high-performance resin systems used in this segment of the industry. End-users also tend to be large, and many are in the aircraft and aerospace businesses. Reinforcement of polymers by strong fibrous network permits fabrication of Polymer Matrix Composites (PMC) characterized by the following properties:

a. High tensile strength;
b. High stiffness;
c. High Fracture Toughness;
d. Good abrasion resistance;
e. Good puncture resistance;
f. Good corrosion resistance;
g. Low cost.

According to the reinforcement material, the following groups of Polymer Matrix Composites (PMC) are used:

a. Fiberglasses – Glass Fiber Reinforced Polymers;

b. Carbon Fiber Reinforced Polymer Composites;
c. Kevlar (aramid) fiber reinforced polymers.

Reinforcing fibers may be arranged in different forms:

a. Unidirectional fibers;
b. Rovings;
c. Veil mat: thin pile of randomly orientated and looped continuous fibers;
d. Chopped strands: thin pile of randomly orientated and looped short (3-4 inches) fibers
e. Woven fabric.

Properties of Polymer Matrix Composites are determined by:

a. Properties of the fibers;
b. Orientation of the fibers;
c. Concentration of the fibers;
d. Properties of the matrix.

2.4 THERMOSETS

According to Bruce (2000), thermosets are network-forming polymers, which include epoxy, phenolic, unsaturated polyester, polyurethane, dicyanate, bismaleimide, acrylate and many others. Unlike thermoplastics, chemical reactions were involved in the used of thermosets. As a result of these reactions the materials first increase in viscosity and eventually cross-linked and become set, as a result, they cannot longer flow or dissolve. Cure was most often thermally activated, which gives rise to the term thermoset, but network-forming materials whose cure was light activated were also considered as thermosets. Some thermosetting adhesives cross-link by a dual cure mechanism that is by either heat or light activation. In the uncured state thermosets are mixtures of small reactive molecules, often monomers. Catalysts are often added to accelerate cure. Most thermosets incorporate particulate fillers or fiber reinforcement to reduce cost, to modify physical properties, to reduce shrinkage

during cure, or to improve flame retardance. Thermosets generally possess good dimensional stability, thermal stability, chemical resistance and electrical properties. Because of these attributes, they find widespread use in several applications such as adhesives; primary and secondary structural members in aerospace; countertops and floors for manufacturing facilities and homes; printed circuit boards, conductive polymer elements, and encapsulation materials for electronic applications; dental materials, especially adhesives; and recreational products such as tennis racquets, bicycle frames, golf clubs and fishing rods. Unlike thermoplastic polymers the processing of thermosets includes the chemical reactions of cure. As illustrated in Fig. 2.2 cure begins by the growth and branching of chains. As the reaction proceeds, the increase in molecular weight accelerates, causing an increase in viscosity, and reduction in the total number of molecules. Eventually several chains become linked together into a network of infinite molecular weight. The abrupt and irreversible transformation from a viscous liquid to an elastic gel or rubber is called the gel point. The gel point of a chemically cross-linking system can be defined as the instant at which the weight average molecular weight diverges to infinity.

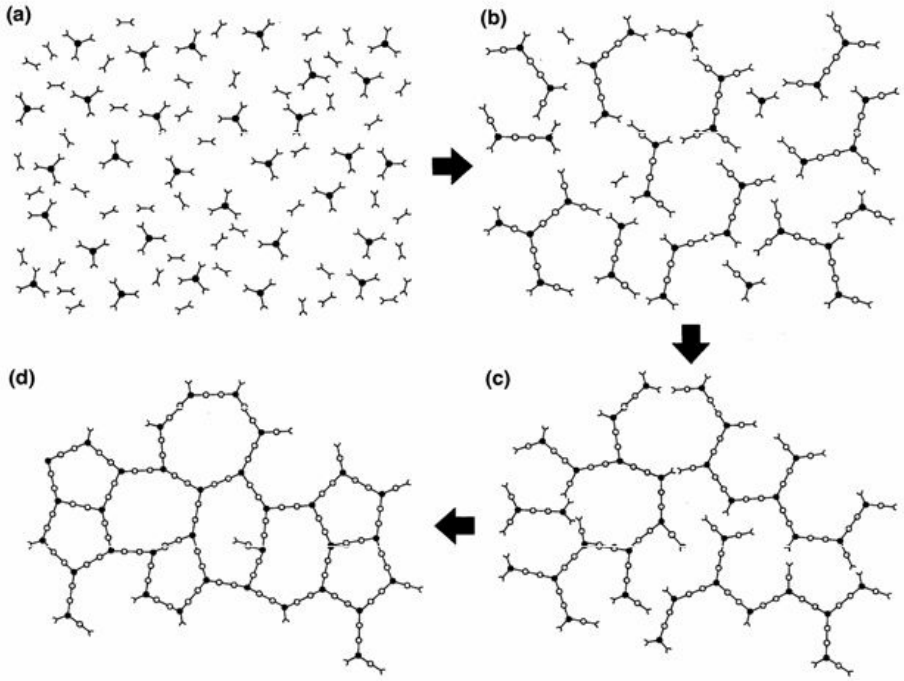

Figure 2.2: Schematic two-dimensional representation of thermoset cure; (a) Cure starts with A-stage or uncured monomers and oligomers, (b) proceeds via simultaneous linear growth and branching to an increasingly more viscous B-stage material below the gel point, (c) continues with formation of a gelled but incompletely cross-linked network and ends with the fully cured and, (d) C-stage thermoset

Source: Bruce (2000)

Some advantages and disadvantages of thermosets are listed as shown in the table below:

Table 2.2: Advantages and Disadvantages of Thermosets

Advantages	**Disadvantages**
Well established processing and application history	Resins and composite materials must be refrigerated
Better economics than thermoplastic (T.P.) polymers	Long process cycles
Better high temperature (H/T) properties	Poor recycling capabilities
Good wetting and adhesion to reinforcement	More difficult repair ability

Source: Bruce (2000)

2.5 THERMOPLASTIC

Vodicka (1996) found that in the area of high performance thermoplastics, polyetheretherketone (PEEK) and polyphenylenesulfide (PPS) are probably the most widely reported thermoplastic resins. Most high performance thermoplastics have a semi-crystalline polymer morphology since levels of crystallinity never exceed about 90%. Crystallinity in high-performance polymers is important as it has a strong

influence on chemical and mechanical properties. In broad terms crystallinity tends to increase the stiffness and tensile strength while amorphous areas are more effective in absorbing impact energy. The degree of crystallinity is determined by many factors including the type of polymer and the processing conditions. In the processing of a particular polymer type, polymer crystals form during cooling from the melt state. The rate of cooling is a crucial parameter in determining the level of crystallinity. According to Roger Vodicka (1996), PEEK thermoplastic resin is characterised by a high melting temperature (Tm) and high glass transition temperature (Tg). It forms a partly crystalline polymer morphology that has a high resistance to chemical attack, radiation and thermal oxidation. PPS has a lower Tg and Tm than PEEK but is extremely thermally stable, has fire retardant properties, can attain a high level of crystallinity and also resistant to many organic solvents. Typical properties of PPS and PEEK resins are listed in Table 2.3.

Table 2.3: Some Properties of PEEK and PPS Thermoplastic Resins

Name (Manufacturer)	Glass Transition Temperature, (Tg)	Melting Temperature (Tm)	Crystallinity
PEEK	143°C	334°C	0-40%
PPS	85°C	285°C	0-65%

Source: Mallick (2007)

Thermoplastic elastomers (TPEs) are rubbery materials with an equivalent elastic performance to that of conventional thermoset rubbers (molded through heat). In addition, they can be processed and recycled like thermoplastic materials. Because of environmental considerations and favorable manufacturing methods, replacement of conventional vulcanized rubber by TPE for industrial applications is growing rapidly. Poly(styrene-b-elastomer-b-styrene) (SEBS)/polypropylene (PP) blends constitute the best-performing elastomers. Fillers can enhance their processability and mechanical compound properties, as well as reduce material costs. Filler

behavior in these compounds is affected by factors like the particle-size distribution, surface area, shape, color, and surface chemistry.

Sreekanth *et al.* (2009) said that thermoplastic elastomers are an important class of engineering thermoplastic elastomers, combines the physical properties of elastomers with the excellent processing characteristics of thermoplastics Polyester thermoplastic elastomer consisting of poly(butylene terephthalate) (PBT), as hard segments and poly(tetramethylene ether glycol terephthalate) as soft segments. The basic structure of polyester thermoplastic elastomer is shown in figure 2.3. Polyester thermoplastic elastomer shows outstanding mechanical properties at temperatures up to 130°C coupled with very good low temperature flexibility. It shows good resistance to tear, impact, abrasion and creep and excellent oil, hydraulic fluids and grease resistance. In order to improve thermal, mechanical and electrical properties of polyester thermoplastic elastomers, particulate fillers such as alumina trihydrate, montmorillonite, clays, talc, mica, silica, flyash, wollastonite, kaolin etc are incorporated. Flakes or platelets represent a special class of reinforcing fillers for thermoplastics and thermosets.

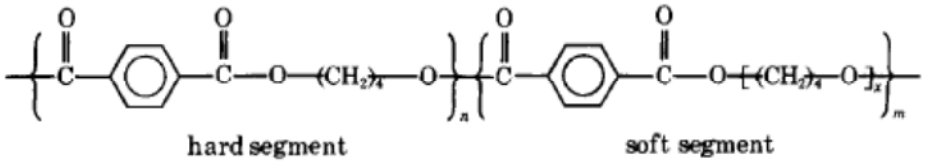

Figure 2.3: Structure of thermoplastic elastomer

Source: Mallick (2007)

2.6 FIBER

Generally, fiber can be divided to 2 major groups, which are natural fiber and synthetic fiber. The examples of natural fiber are:

i. Vegetable fiber- generally based on arrangements of cellulose, often with lignin: examples include cotton, hemp, jute, flax, ramie, and sisal. Plant